Short-term intense burst of Saturn kilometric radiation: relationship to the rotation phase and north-south difference

D. Maruno[1], Y. Kasaba[1], T. Kimura[2], A. Morioka[1], B. Cecconi[3]

[1] Department of Geophysics, Tohoku University
[2] ISAS, JAXA
[3] LESIA, Observatorire de Paris

Introduction - Short-term variations of SKR

Transient variations of SKR

✓ Saturn kilometric radiation (SKR) spectra sometimes show the intensification of its main frequency band with the extension to lower frequencies. We refer to this as the "**short-term intense burst**" of SKR (hereafter simply as the burst). The lower-frequency extension can be interpreted as the extension of SKR source regions to higher altitude.

✓ These bursts are related to **magnetic reconnections** in the Kronian magnetotail [e.g., Jackman et al., 2009]. There are two main candidates that occur reconnections: the internal driver (planet rotation) and external driver (solar wind) [Cowley et al., 2004]. The relationship between solar wind compressions and SKR burst has been shown [e.g., Jackman et al., 2005; Badman et al., 2008]. However, It is still in question which driver is dominant for reconnections.

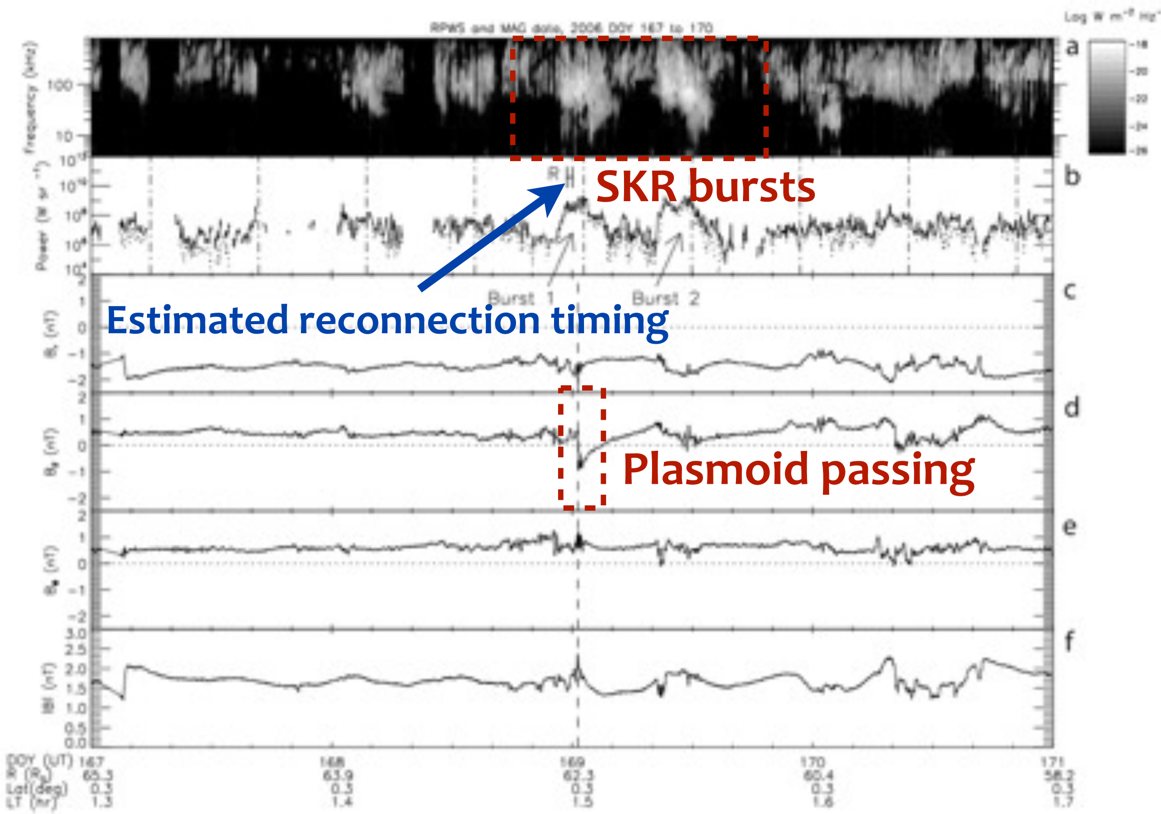

Fig. 1. An example of SKR bursts [Jakman et al., 2009]. The reverse of the sign of B_θ on 169 means that the reconnection in the Kronian magnetotail occurred.

Phase relations of SKR bursts

✓ Jackman et al. [2009] showed the link between reconnection events with SKR bursts almost and the SKR rotational modulations. On the other hand, Badman et al. [2008] reported the timings of SKR bursts were sometimes independent of the modulations. These result may provide us clues for the mechanism of the SKR burst, related M-I coupling systems. At any rate, It would be **necessary to examine phase relations of SKR bursts with north-south separation** because the north-south difference of SKR modulation (as described below) have been discovered.

Introduction - Rotational variation of SKR and SKR phase

SKR rotational modulations & their long-term variations

- ✓ SKR show the rotational modulations with the **north-south asymmetric periods** [Kurth et al., 2008; Gurnett et al., 2009] , and they are time-variable [Galopeau and Lecacheux, 2000; Gurnett et al., 2005]. Similar features are discovered, for example, in the magnetic field and aurorae.

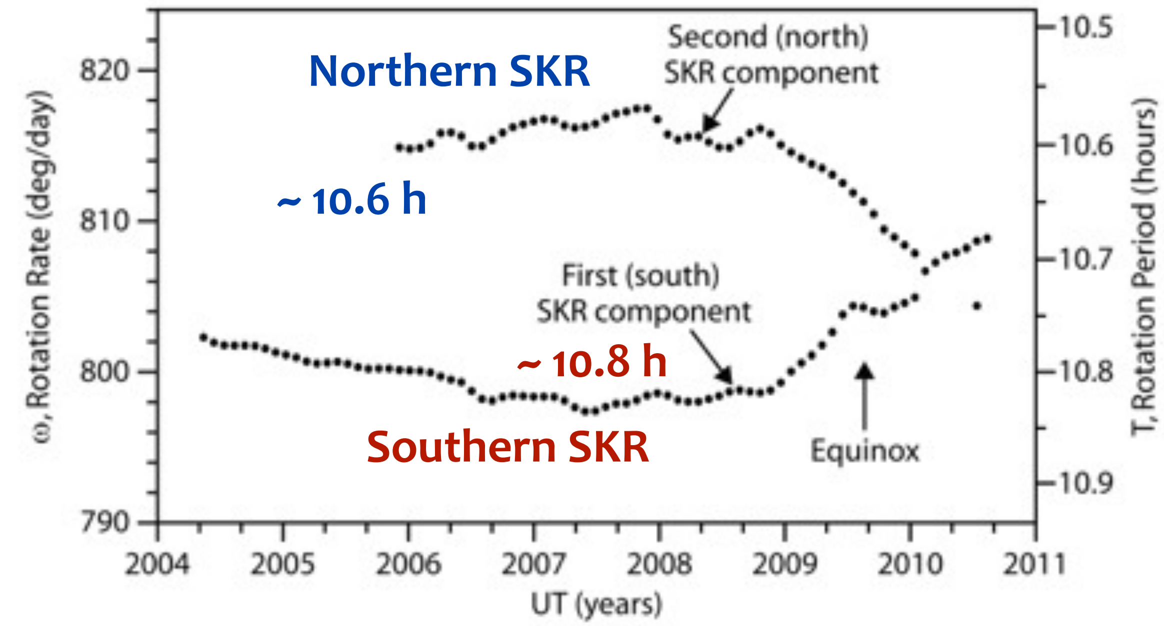

Fig. 2. Long-term variation of northern and southern SKR modulation periods [Gurnett et al., 2010]

Northern and Southern SKR phase systems

- ✓ Using continuous SKR periods, a separate phase system was built for each hemisphere from 1 January, 2004 to 12 July, 2010

$$\Phi_{S,N}(t) = \int \frac{360}{T_{S,N}(t)} dt + \Phi_{0,S,N} \qquad \text{(modulo 360°)}$$

↑northern/southern period

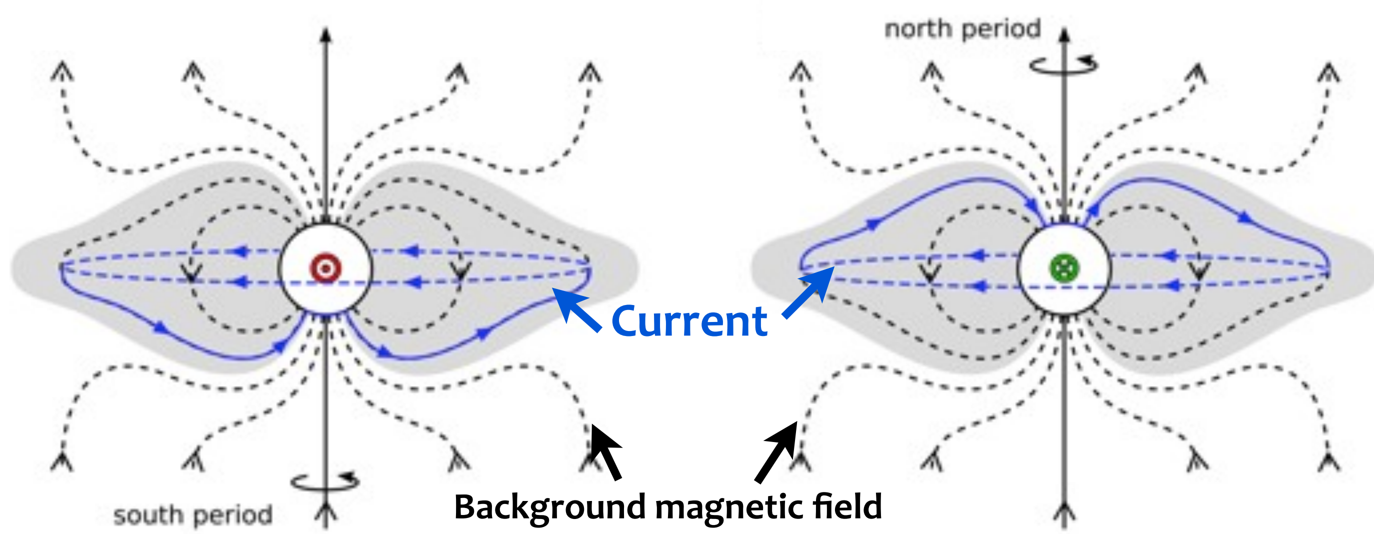

Fig. 4. North-south asymmetric FAC systems proposed to explain the north-south asymmetric field modulations [Andrews et al., 2010].

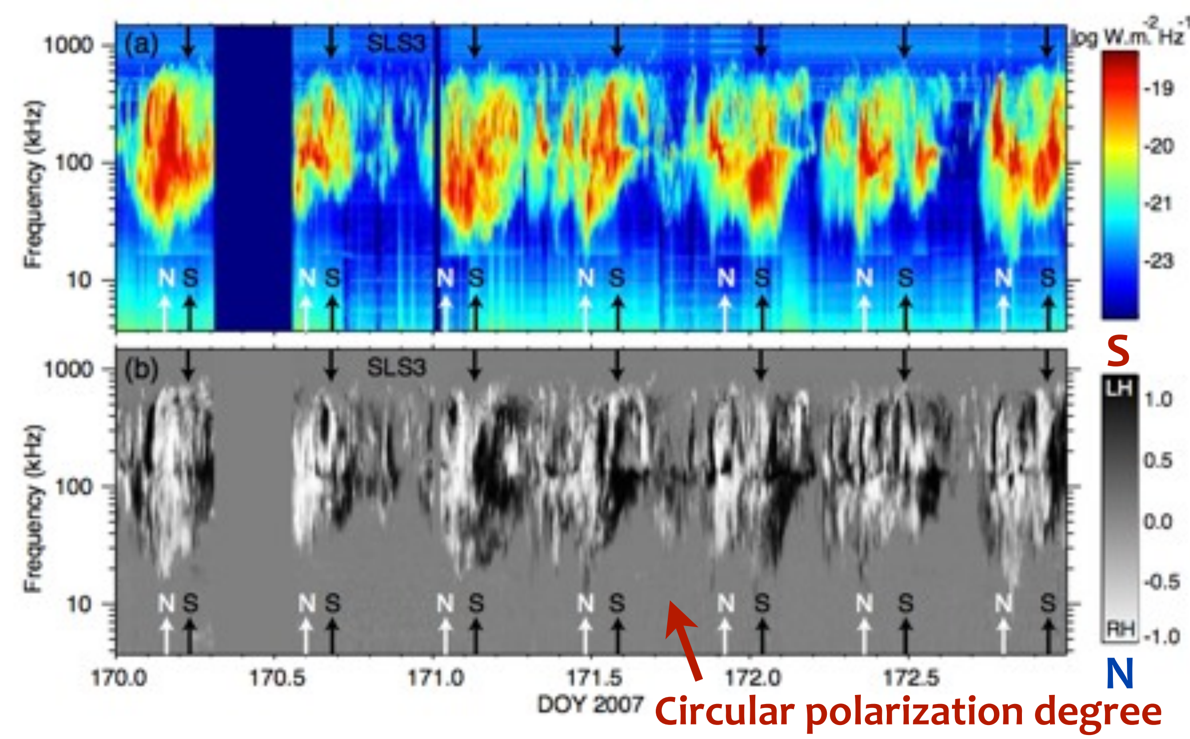

Fig. 3. Difference between northern and southern SKR phases in 2007 [Lamy, 2011]. When SKR intensities become maximum, SKR phase = 0°.

Introduction - Similar events of AKR at Earth

Substorm and AKR burst

- At Earth, auroral kilometric radiation (AKR) shows the two step evolution associated **with substorm onset** [Morioka et al., 2010].
- They proposed a substorm scenario where an Earthward flow burst generated by midtail reconnection caused the first-step evolution of substorm (low-altitude acceleration), and the subsequent instability driven by enhanced FAC in the M-I coupling region ignited substorm breakup.
- The instability can be kept up by FAC increased by flow bursts in the tail or electron density decreased by parallel electric fields.

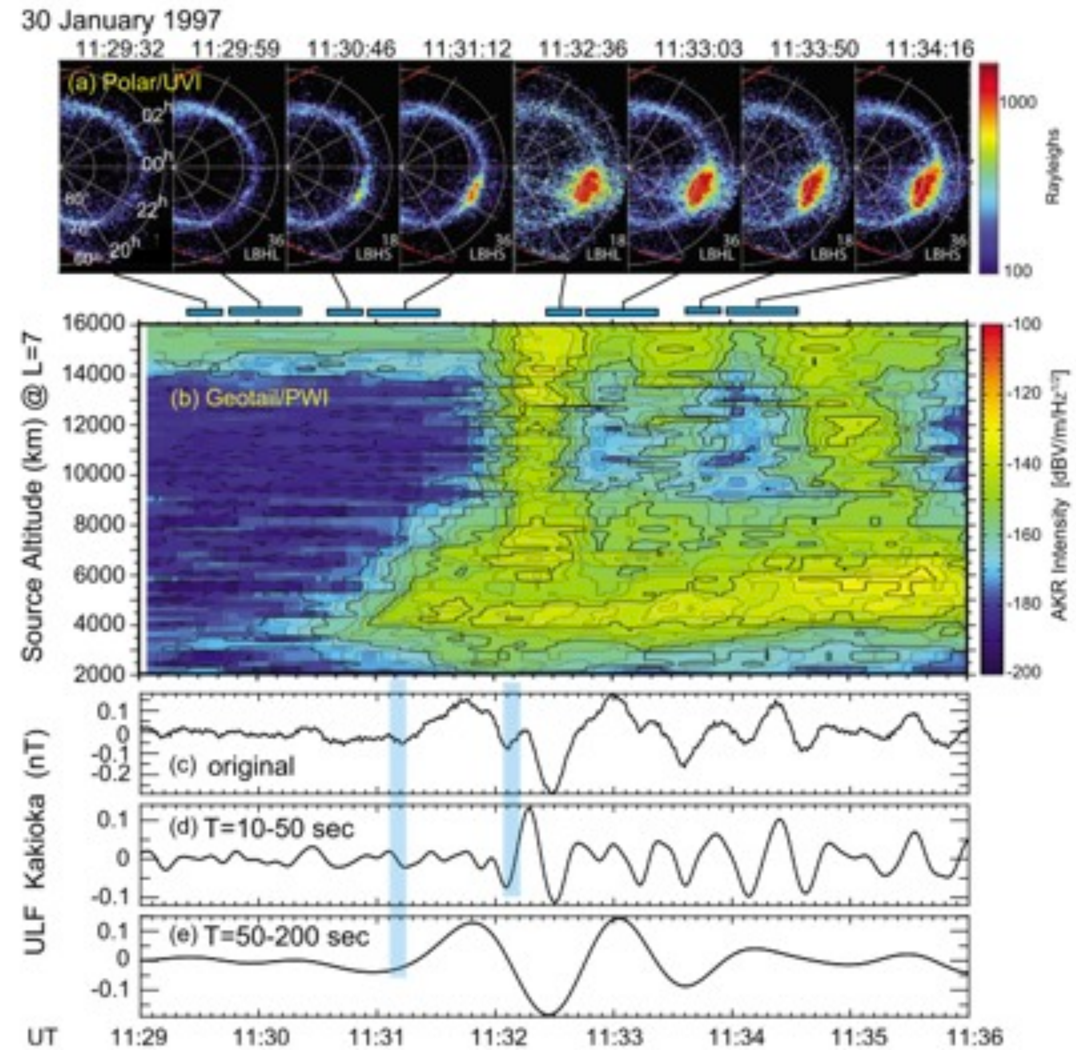

Fig. 5. Two step evolution of AKR [Morioka et al., 2010]. (Top) auroral brightness, (middle) AKR intensity, (bottom) geomagnetic activities.

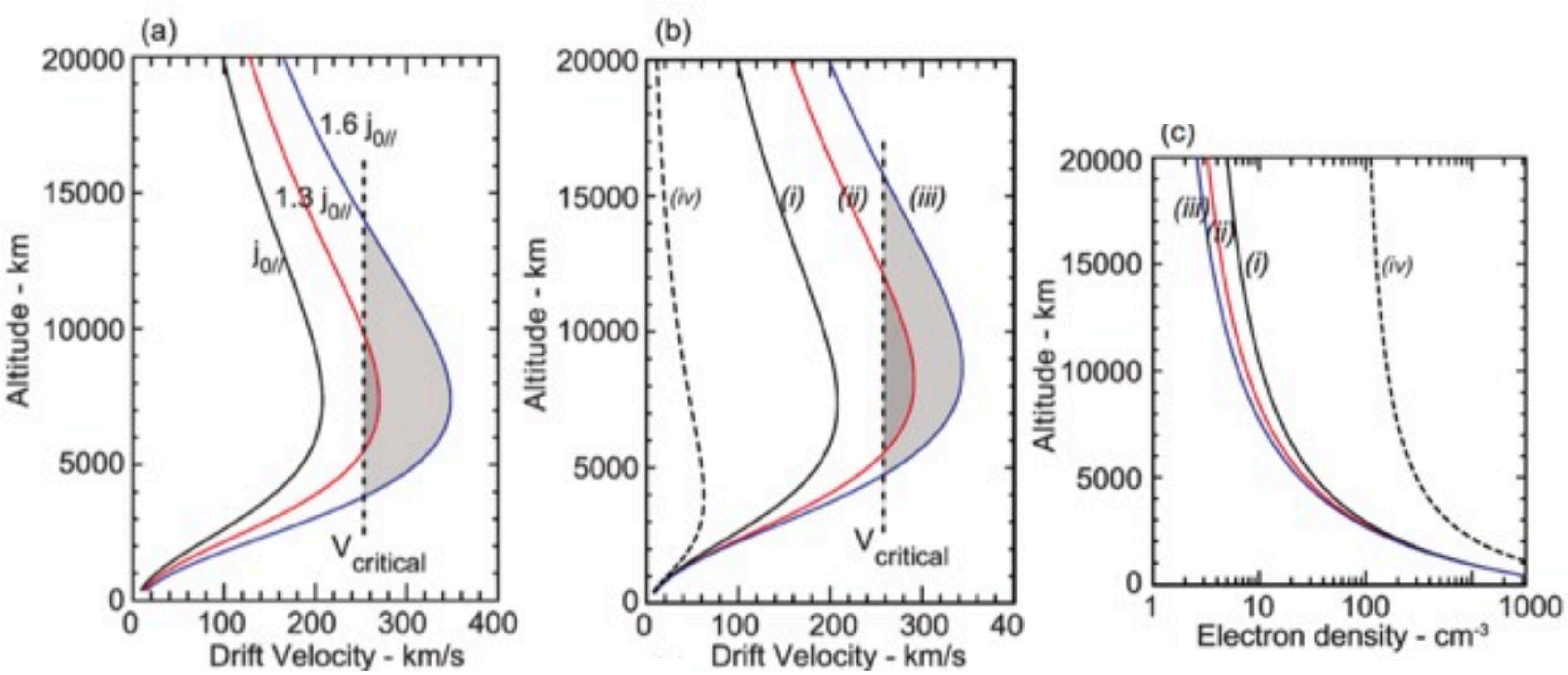

Fig. 6. Drift velocities of FAC-carrying electrons [Morioka et al., 2010]. $V_{critical}$ is the drift velocity enough to cause current/current-driven instability.

Purpose of this study

In this study, we focus on **the short-term intense bursts of SKR**, which would provide clues to the following problems:

1. **What drives magnetic reconnections in the Kronian magnetotail ?**

   According to the previous studies, SKR bursts are associated with magnetotail reconnections. It is useful to determine the dominant driver to investigate timings of SKR bursts and to compare them with solar wind parameters.

2. **How the ionosphere and magnetosphere couple each other ?**

   M-I coupling systems, which have north-south asymmetry have been proposed to explain several periodic modulation at Saturn. If SKR bursts are related to FAC systems, they should also show the north-south asymmetry. We examine if they are asymmetric for the first time.

3. **What is the difference between Saturn and Earth's radio bursts ? And what causes them ?**

   AKR bursts are well examined with multi instruments. The comparison will contribute to answer to the above questions.

The first step:

We examined the relation between SKR bursts and SKR phase and compared northern and southern SKR bursts during the pre-equinox.

Datasets and SKR visibility

We imposed the following orbit conditions to minimize visibility effects which are caused by SKR beaming features.

Orbit condition

- ✓ Interval : DOY 268 2005 - 240 2006
- ✓ Spacecraft radial distance : 10 - 100 Rs
- ✓ Spacecraft latitude : - 5 - + 5 deg
- ✓ Spacecraft local time : all

SKR polarization data

RH and LH SKR power, flux density observed by Cassini/RPWS.
3 min time res., 24 log-spaced (3.5 - 320 kHz) and 24 linearly-spaced freq. band, normalization to 1 AU [Lamy et al., 2008].

SKR phase data

Northern and southern SKR phase. 3 min time res., accessed through the Cassini/RPWS/HFR data server http://www.lesia.obspm.fr/kronos.

Cassini orbit data

Cassini's radial distance, latitude, local time. 3 min time res., accessed through http://www-pw.physics.uiowa.edu/SLS4/.

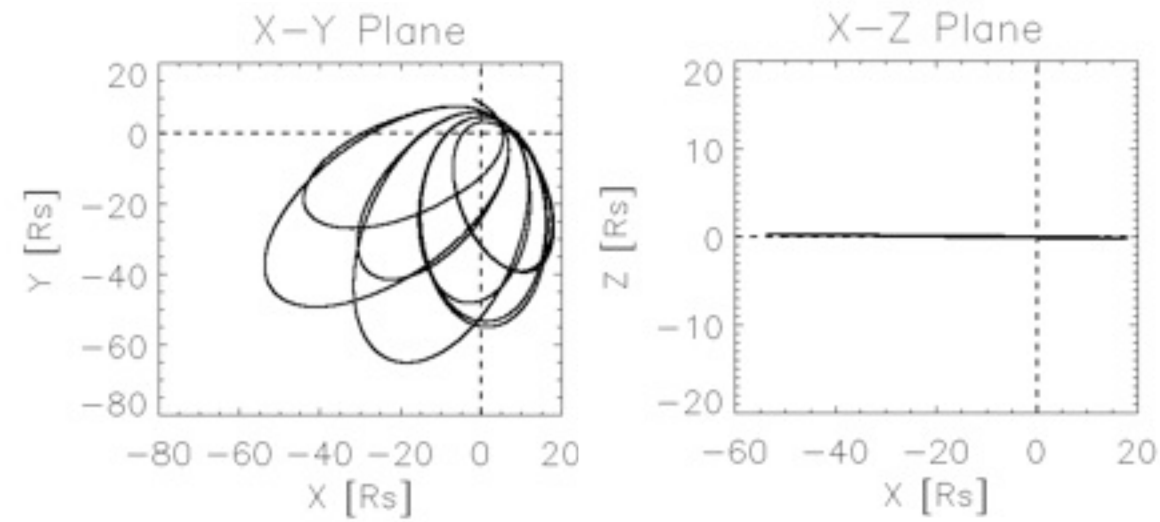

Fig. 7. Cassini's orbit from 268 2005 to 240 2006.

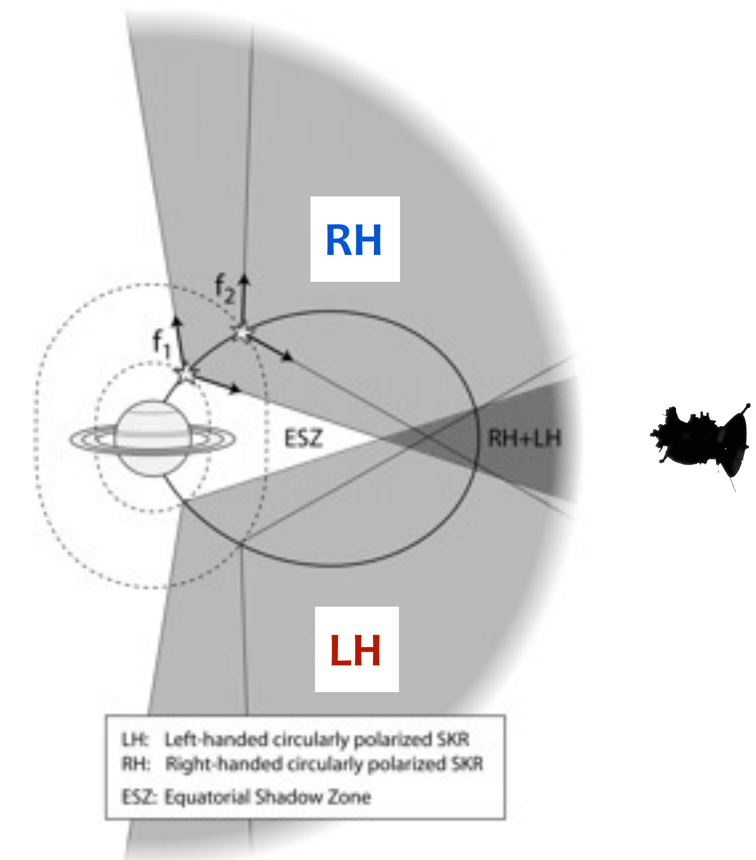

Fig. 8. Visibility effects of SKR emissions [Lamy et al., 2008].

Selection criteria for SKR bursts

We use the following selection criteria to define the short-term intense burst of northern and southern SKR. We impose strict so that we select distinguished events. This may result in **underestimation** of SKR burst events.

1. Criterion for the lower-frequency extension

Median SKR flux density from 10.1 to 45.6 kHz must be larger than the 75 % value of those over 10 rotations around a SKR burst event at an arbitrary phase.

2. Criterion for the enhancement of SKR power

Emitted SKR power integrated between 10 to 1000 kHz must be larger than the 75 % value of those over 10 rotations around a SKR burst event at an arbitrary phase.

3. Criterion to exclude low frequency narrowband emissions

There must not be obvious spectral gaps between 10.12 to 205.027 kHz.

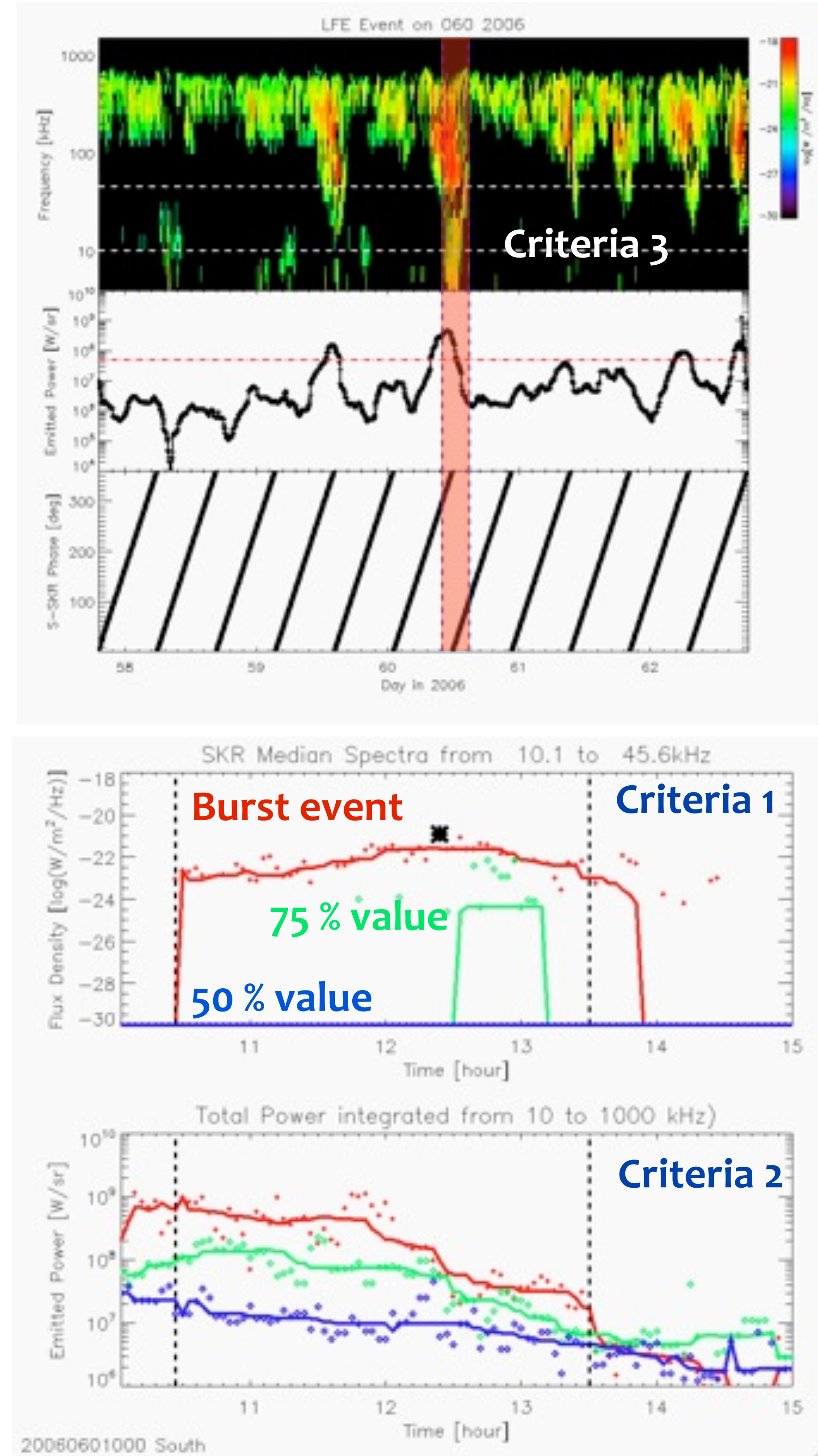

Fig. 9. An example of the an SKR burst event.

Result - Statistics of SKR short-term intense bursts

Main findings of this study:

1. We identified 15 and 35 SKR burst events in the northern and southern SKR, respectively.
2. More than 60 % of SKR burst events occurred when the northern/southern SKR phase is 0 ± 60 °, that is, they were in phase with northern and southern SKR rotational modulations, respectively.
3. 7 pairs of northern and southern SKR bursts took place almost simultaneously (within 2 hours).
4. Duration time of SKR bursts were usually less than 4 hours.
5. Cassini's radial distance and local time where SKR bursts frequently occurred were 40 - 50 Rs and 0 - 10 hours, respectively.

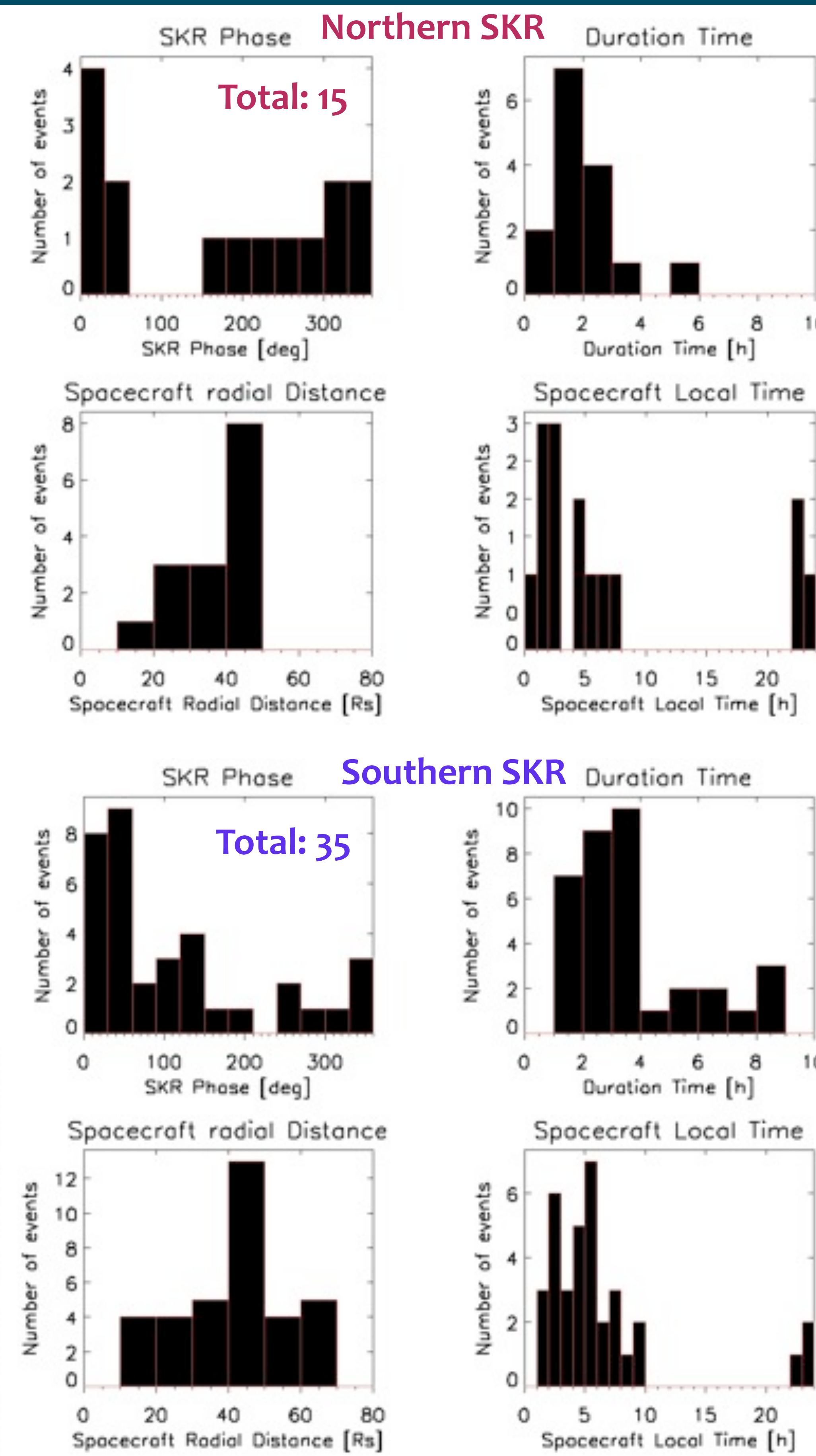

Fig. 10. Histogram of number of SKR short-term intense burst events that fulfill the criteria as a function of SKR phase, duration time, Cassini's radial distance and local time.

Discussion - Assumptions

Assumptions

A. We consider the main reconnection divers are an internal driver (mass-loading) and an external driver (solar wind).

B. We discuss the results with the assumption that the evolution process of AKR burst proposed by Morioka et al. [2010] can be approximately applied to Saturn. They proposed the following process: First, reconnections in the Earth's magtetotail cause plasma flow bursts Earthward. Then, FACs enhanced by the bursts make the AKR main band intensified. If the electron drift velocity in the M-I coupling region reaches a certain threshold, the lower-frequency extension of AKR spectra triggered.

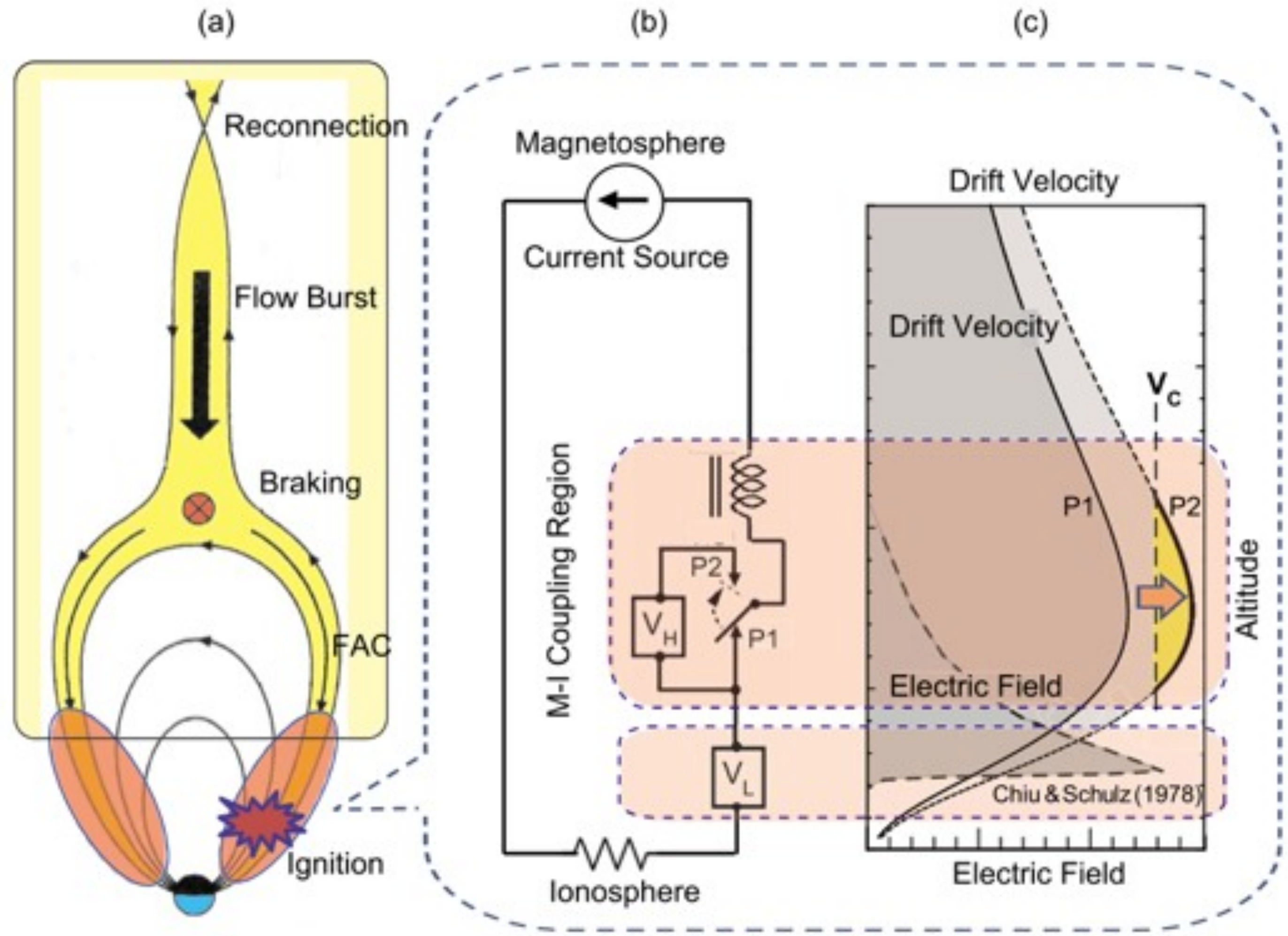

Figure 11. The mechanism of AKR bursts proposed by Morioka et al. [2010]

Discussion - for result 1

Each numbers correspond to ones in the result page.

1. The result shows the number of southern SKR bursts was more than double the number of northern SKR bursts. Badman et al. [2011] pointed out the north-south asymmetry of IR main oval, and they suggested that the hemispheric asymmetry in the main oval could result from the **reduced ionospheric conductivity in the northern hemisphere.** Kimura et al. [in preparation] have been discovered the similar asymmetry of SKR intensities. The post-equinox analysis is necessary to clarify if the difference in conductivities cause the asymmetry of SKR bursts.

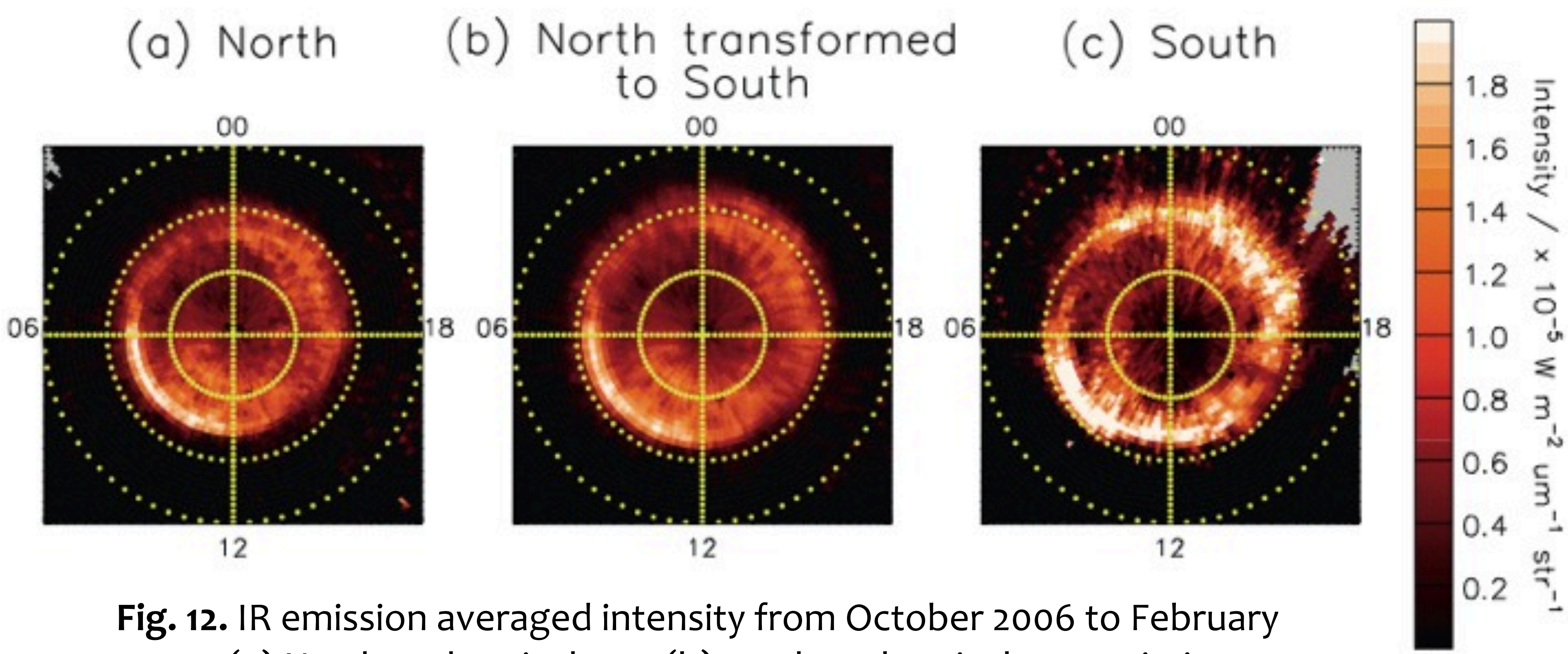

Fig. 12. IR emission averaged intensity from October 2006 to February 2009 . (a) Northern hemisphere, (b) northern hemisphere emission magnetically mapped into the southern hemisphere and (c) southern hemisphere. [Badman et al., 2011]

Discussion - for result 2, 3

Each numbers correspond to ones in the result page.

2. 3. The two distinct phase dependence support the north-south asymmetric coupling FAC system proposed by Badman et al. [2012] based on the one suggested by Andrews et al. [2010]. The system contains two FAC systems: **the rotating and the LT-fixed FAC system** to explain the north-south asymmetry and LT dependence of auroral emissions.

The result indicates flow bursts triggered by tail reconnections rarely generate enough current to extend the SKR spectra down to lower-frequency.

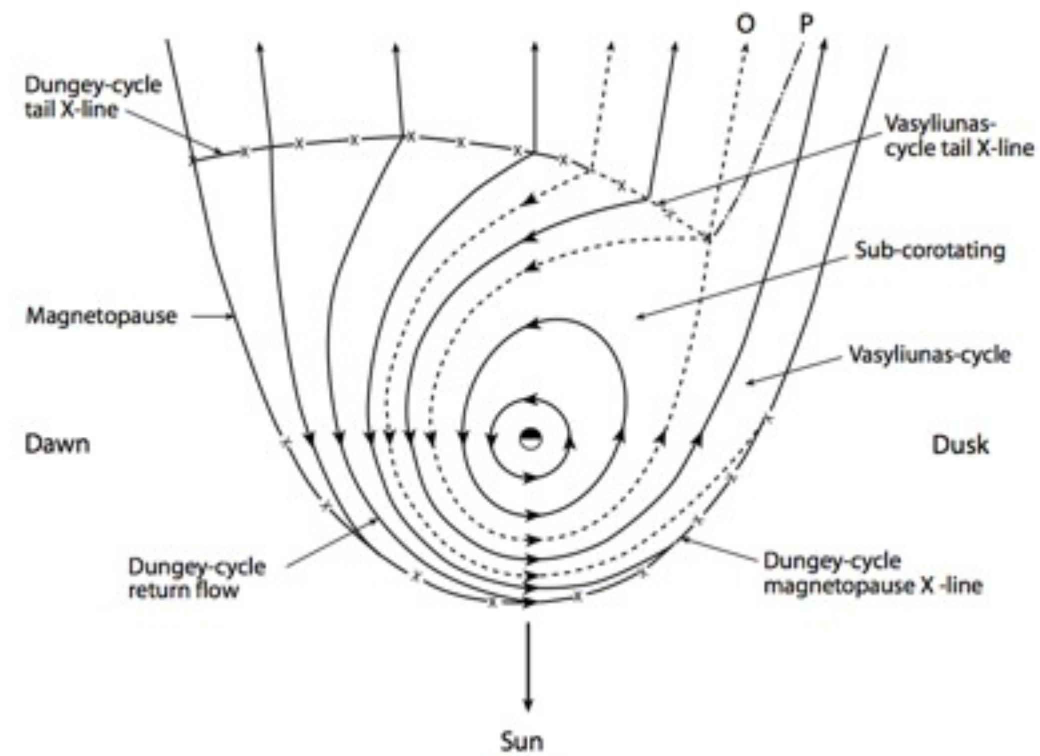

Fig. 13. Sketch of plasma flow in the equatorial plane [Cowley et al., 2004]

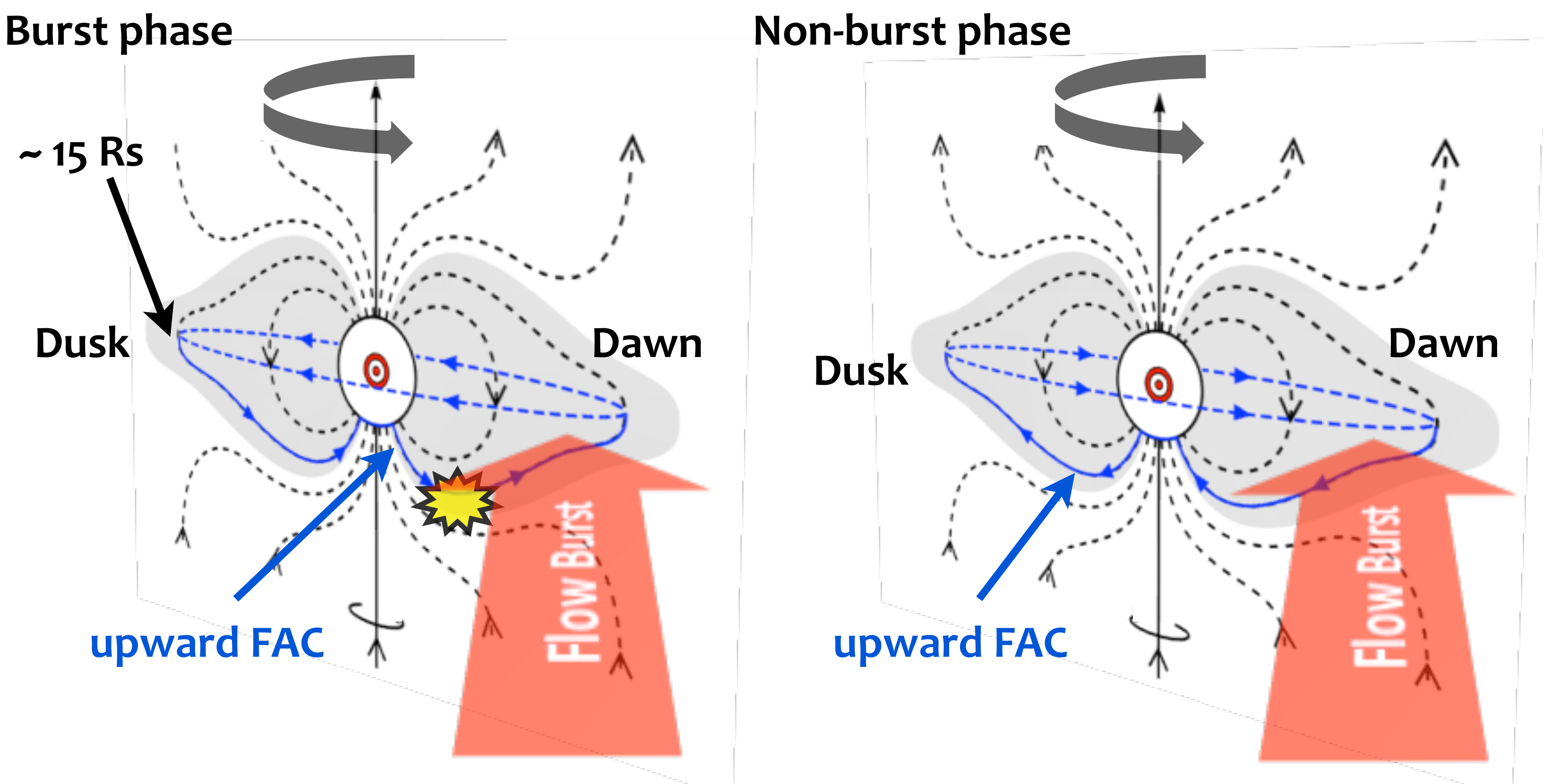

Fig. 14. Concept image which may explain the SKR phase dependence of SKR bursts with the north-south asymmetry. Only the southern FAC system is shown.

+ LT-fixed current system ?
(with the upward FAC region on dawn)

Distinct phase dependence

Discussion - for result 4, 5

Each numbers correspond to ones in the result page.

4. The typical duration time of the SKR burst is 0 - 4 hours. It is an order of magnitude longer than Earth's case. If the analogy with AKR bursts is available, it is **associated with the duration time of the flow burst and the decrease of background plasma density.** Jackman et al. [2011] showed the average duration time of a post-plasmoid plasma sheet was 58 min. if we regard it as the average duration time of a reconnection, it does not conflict with our result. However, Duration times of SKR bursts may contain visibility effect of SKR.

5. The result would suggest that more SKR bursts occur on the dawn side. However, Cassini spent about 30 % of its traveling time on orbiting at between 40 - 50 Rs and 80 % on orbiting at between 0 - 10 hours from 268 2005 to 240 2006. This may affect the statistical result.

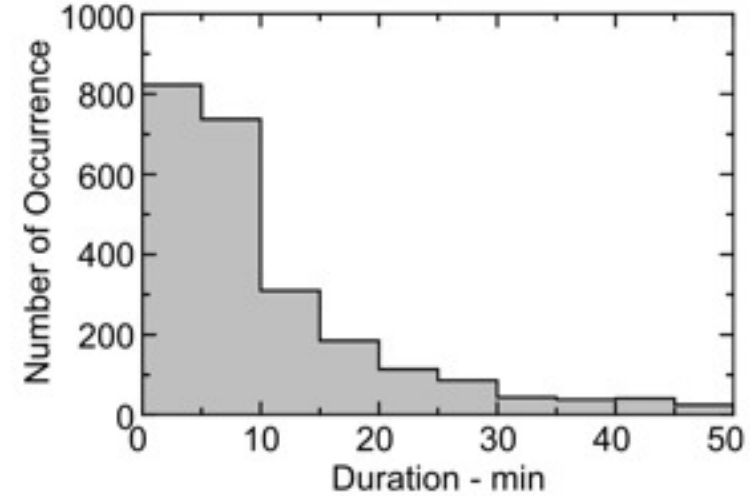

Fig. 15. Histogram for duration of the lower-frequency extension of AKR [Morioka et al., 2012].

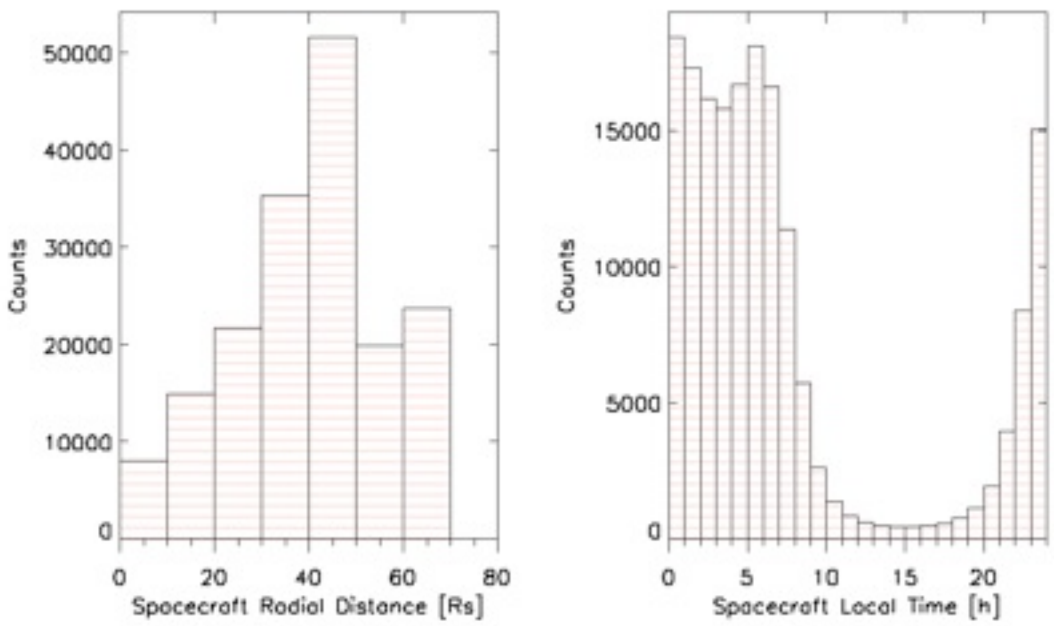

Fig. 15. Histogram for the Cassini spacecraft trajectory from 268 2005 to 240 2006.

Summary

✓ In this study, we examined characteristics of the short-term intense bursts of SKR with the separation of northern and southern SKR from 268 2005 to 240 2006. The result mainly shows the dependence of the number of SKR bursts between each hemisphere and the north-south asymmetric phase dependence, suggesting that Saturn has a **M-I coupling system separated into northern and southern hemispheres**. This is consistent with results derived by the Kronian magnetic field perturbations, aurorae and SKR rotational modulations

Future work

✓ Similar analyses during **post-equinox** interval, when the apogee of Cassini located on the dusk side, are essential to confirm the above discussions.

✓ **Comparison with solar wind parameters** will give us clues about reconnection drivers.